Feb. 3, 1948. A. H. ROSENTHAL 2,435,548

HIGH VACUUM PUMP

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Fig. 2.

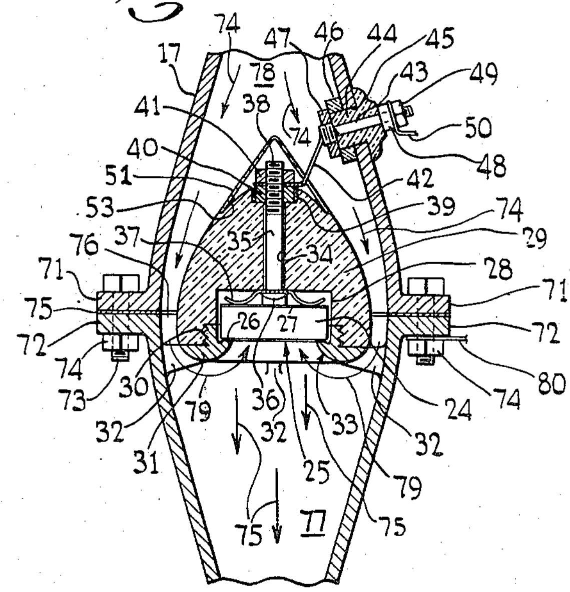

Fig. 1.

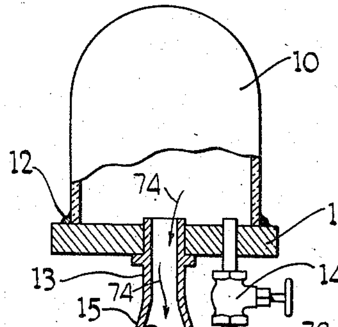
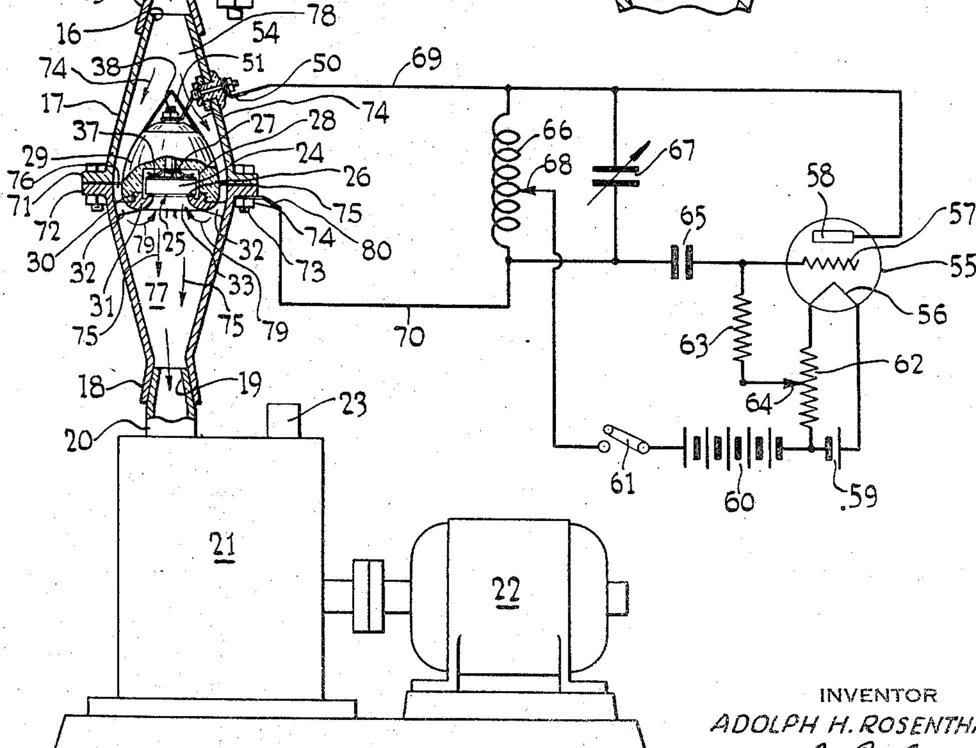

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Fig. 3.

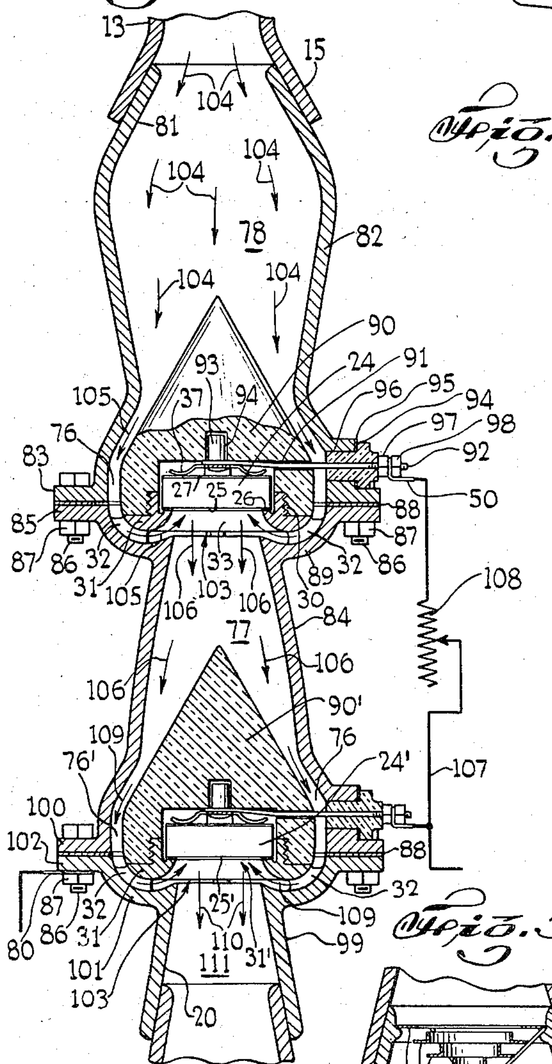


Fig. 4.

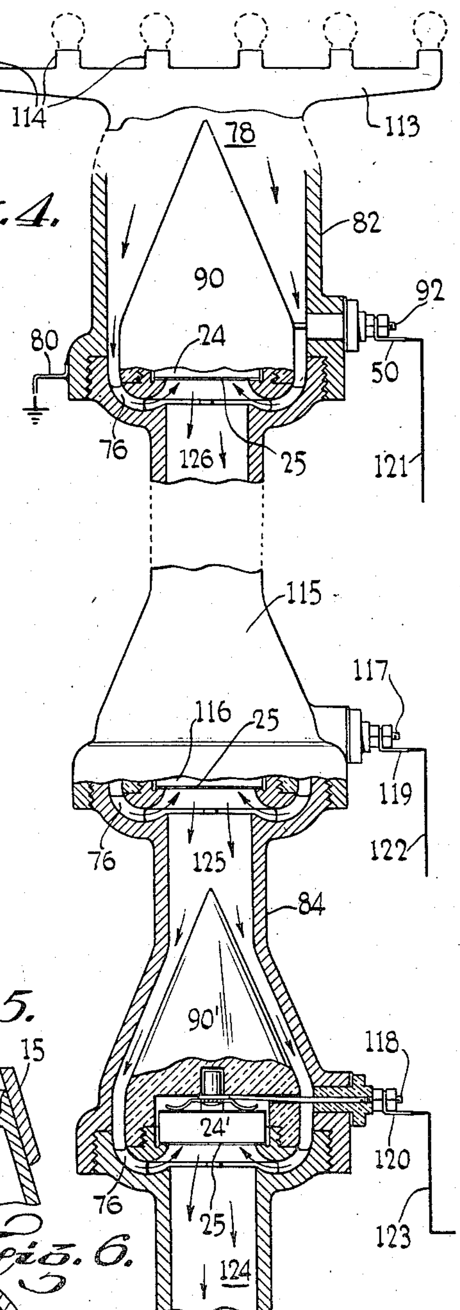


Fig. 5.

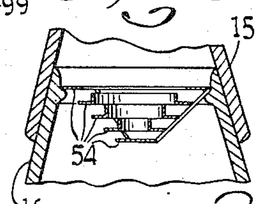
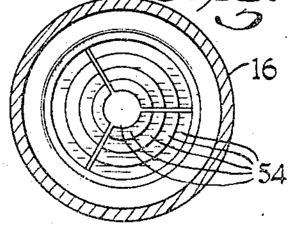


Fig. 6.



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UNITED STATES PATENT OFFICE

2,435,548

HIGH VACUUM PUMP

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Application November 5, 1943, Serial No. 509,144

14 Claims. (Cl. 230—1)

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This invention relates to a method and apparatus for rarefying vapors or gases, in particular air, within confined space and thereby producing a vacuum of desired high degree. Single- or multi-stage pumps have been suggested for this purpose, working on different principles.

In pumps operating on the injector principle, a liquid, preferably water or mercury, or vapor was injected through a nozzle into the confined space either in a solid or whirling jet which imparted an impetus to the gas as well as trapped some of it, and upon leaving the confined space carried along thus accelerated and trapped gas.

The effect of this type of pump was limited by the vapor pressure developed by the liquid or vapor used as a working medium which depends on the prevailing temperature. The low pressure obtainable by this type of pump is thus limited and they are used mostly for producing vacua of moderate degree and as auxiliary or backing pumps for other, more efficient vacuum pumps.

Another type of pump used in the vacuum technique for producing moderate vacua is of the reciprocating piston type, the efficiency of which was increased by filling its dead spaces or clearances with liquids of high boiling point, such as oil or mercury. Here again the vapor pressure of these liquids limited the degree of vacuum attainable by their use; leakage losses in the valves and through the packings of the piston rod, etc., caused additional difficulties. The vacuum attainable by this type of pump is considerably better than that of ejector pumps, but does not suffice to produce high vacua as required in many branches of today's vacuum technique and they are used, therefore, as auxiliary or backing pumps to produce a "pre-vacuum" for more effective pumps of other types. Rotating pumps of the vane and gear type are of similar effect and use.

Vacuum pumps which permit the production of extremely high vacua, i. e. extreme rarefaction and consequential extremely low pressures of a gas, operate either on the principle of gas diffusion into streaming, particularly injected vapors of mercury or oil, or on the "molecular" principle. The performance of the vapor diffusion pumps is limited by the vapor pressure of the working medium, and their operation is complicated by the heating means required for vaporizing the working medium, and by cooling means. The "molecular" pumps make use of the quite fundamentally changed behaviour of gas when its rarefaction is extended so far that the "mean free path" of the individual gas molecules is larger than the dimensions of the space in which the gas is confined.

At a given temperature, the pressure of a gas is proportional to the number of gas molecules in a unit of volume. At atmospheric and considerably lower pressure, the gas molecules within a unit of volume fly irregularly in every direction, collide frequently and change thereby the directions of their flight. Hence the direction of flight of the individual gas molecule is undefined. Even if an impact is exerted upon it in a certain direction, its thus directed path will be terminated soon upon collision with other molecules. However, if the rarefaction of the gas exceeds a certain degree (and the gas pressure is thereby reduced below a certain value), the average or mean path which a molecule follows freely without colliding with another one, is extended so far that its hitting upon and being reflected by the wall of the confined space is much more likely than its colliding with another gas molecule. In such a state of rarefaction and at such a low pressure in the gas, the individual gas molecules are therefore eminently capable of being directed by a moving surface upon which they impinge. The mean free paths of the molecules of various gases used in the vacuum technique at decreasing gas pressures have been calculated and verified by experiments, and are therefore well known. With air, a state in which the mean free path of its molecules exceeds usual dimensions of spaces in which the air is to be rarefied, is attained at pressures of about 0.001 mm. mercury column, and such and lower air pressures are commonly termed a true high vacuum.

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The "molecular" pump type utilizes this behaviour of gas under low pressure. The molecules of a pre-rarefied gas are admitted to the pump space and permitted to impinge upon the circumference of a rapidly rotating drum which reflects as well as imparts to them a velocity component in the direction of its rotation; the thus repeatedly reflected molecules are transported towards and through the outlet of the pump space into another space. As a consequence, the number of gas molecules in that other space is increased, resulting in increase of pressure, while the space from which the gas molecules flew upon the circumference of the rotating drum is depleted of gas molecules and the pressure therein reduced, finally resulting in an extremely high vacuum. The efficiency of this type of pump and the degree of vacuum attainable are limited by the maximum circumferential speed of the rotating drum on which its effect depends, by inevitable leakage in the bearings of the drum shaft, etc.

The invention is concerned with a method of rarefying vapors and gases and an apparatus or pump therefor which also utilizes the behaviour of a sufficiently pre-rarefied gas (or vapor) just described, viz. that its molecules can be directed and accelerated effectively by mechanical action upon them, and it is an object of the invention to improve vacuum pumps, particularly high vacuum pumps working on this "molecular" principle.

In particular, it is an object of the invention to eliminate the disadvantages attendant upon diffusion or diffusion-ejector high vacuum pumps which use vapors of boiling liquids, and to do away with the heating and cooling means of those pumps. According to the invention, no liquids and vapors are used at all for producing the high vacuum.

It is another object of the invention to eliminate rotating or reciprocating members of a high vacuum pump, such as used heretofore in the rotating molecular pump or with reciprocating piston pumps in which the clearance is reduced by means of high boiling liquids. Thereby the difficulties attendant upon these pumps as to fast moving parts and leakages in bearings of a drum shaft or packings of a piston rod, etc. are avoided.

It is still a further object of the invention to increase the efficiency of the mechanical action upon the gas molecules of a pre-rarefied gas, by subjecting them to an immediate directing impact by a vibrating surface rather than reflection by a surface which rotates at high speed in one direction.

It is a further object of the invention to utilize the effect of supersonic vibrations of a mechanical vibrator upon gas, for producing high vacua or extremely low gas pressures.

It is still another object of the invention to provide a method of producing high and highest vacua and a relatively small and compact apparatus therefor, the active elements of which are entirely within the space in which the gas undergoing rarefaction is confined, are stationary and actuated electrically, and the intensity of action of which can be regulated electrically from outside the confined space without resort to any movable part passing a wall of that space.

These and other objects of the invention will be more clearly understood when the specification proceeds with reference to the drawings in which Fig. 1 shows rather schematically in vertical cross-section, with parts in elevation, a single-stage high vacuum pump according to the invention and diagrammatically an electric circuit for exciting supersonic mechanical vibrations of a vibrator used by the invention, Fig. 2 in vertical cross-section and at a larger scale the arrangement of a piezo-electric vibrator in the example of Fig. 1, Fig. 3 in vertical cross-section and partly in elevation a two stage pump according to the invention, Fig. 4 in a similar manner a multi-stage pump according to the invention connected with a manifold for evacuating bulbs, and Fig. 5 in vertical cross-section and Fig. 6 in a view from below, the arrangement of baffles in back of a vibrator unit as used by the invention and shown in Fig. 1.

Referring to Fig. 1, there is shown as a vessel or container to be evacuated, a bel-jar 10, e. g. of steel or glass, placed upon a pump plate 11, e. g. of steel, the upper surface of which is preferably ground and polished so as to provide an air-tight fit with the equally ground lower edge of bell-jar 10. Sealing wax or a gasket 12 may be applied between the bell-jar and pump plate. A pipe 13 is air-tightly fitted into a corresponding aperture of plate 11 and conically widened at its lower end 15. A duct provided with a manually operated valve 14 passes another aperture in plate 11 and is air-tightly mounted therein; valve 14 permits the interior of jar 10 to be connected with and shut off from the surrounding atmosphere.

A longitudinal vessel 17, e. g. of steel, open at and tapering towards both of its ends engages with its uppr end 16 the interior of conical end 15 of pipe or duct 13. The engaging surfaces of the ends 15 and 16 are preferably ground into one another in order to secure an air-tight connection; they may be sealed additionally with a suitable sealing compound. The lower end 18 of vessel 17 is conically enlarged and fitted upon an equally conical end 19 of an intake duct 20 leading to the suction side of a pre-vacuum pump 21. The engaging surfaces of the conical parts 18, 19 are preferably ground into one another and sealed, in order to secure their air-tight connection. Vacuum pump 21 is of any type suitable to produce a pre-vacuum, such as a vane-pump, and driven by an electromotor 22. 23 is an outlet of vacuum pump 21.

A mechanical vibrator capable of being electrically excited to supersonic vibrations of suitably high frequency, preferably of between about 100,000 to 10,000,000 cycles per second is arranged within vessel 17. The vibrator consists in this exemplification of the invention of a piece 24 of piezo-electric material, such as quartz, tourmaline, Rochelle salt, etc. The piece is cut from crystalline piezo-electric material in well known manner, along two parallel planes which are perpendicular to a polar axis of the piezo-electric crystal; such cuts of quartz crystals are known for instance as "Curie-cut" or "X-cut." Some piezo-electric crystals, e. g. quartz crystals, exhibit more than one, e. g. three polar axes, and the distant parallel planes along which the piece is cut from the crystal, may be perpendicular to any one of them. The direction of the mechanical resonance vibrations excited in a thus cut piece may be parallel to the selected polar axis and therefore perpendicular to said parallel planes. The vibrations in the direction of one of those polar axes produced by an alternating electric field in the direction of this axis are termed "longitudinal" or "thickness" vibrations, and their resonance frequency depends mainly on the thickness of the piece. Although other types of vibrations, such as transverse vibrations may be produced and utilized, thickness vibrations are generally preferred. The vibrations can be excited by application of recurrent electric impulses or oscillatory energy, particularly of a sinusoidal voltage to suitable electrodes placed upon two distant parallel planes, and the vibrations are particularly strong if the frequency of the alternating electric voltage essentially equals the mechanical resonance frequency of the piece within narrow range. The crystal piece may also be excited to vibrations of an odd integer multiple frequency of its fundamental resonance frequency, and such odd harmonic vibrations can be used to advantage by the invention. The energy of the mechanical resonance vibrations depends upon that of the applied electric impulses; voltages from several hundred to several thousand volts can be used.

Now referring to Figs. 1 and 2, it is assumed that crystal piece 24 is cut from a quartz crystal in such manner that thickness vibrations result, and that it has the shape of a cylindrical plate the cylindrical circumference of which is parallel and the plane front surfaces of which are perpendicular to the selected polar axis. Front surface 25 is essentially freely exposed and contacted near its edge only by a ring-shaped electrode 26; the rear surface of piece 24 is covered by an electrode 27. The ring and full electrodes may be cut from metallic sheet material and pressed or cemented onto piece 24, or one or both of them may be applied to piece 24 by vacuum evaporation or sputtering upon the respective surface suitable electrode material such as copper, aluminum, etc. The electrode on front surface 25 may also consist of a thin metal layer completely covering that surface and produced or applied in a similar way as the rear electrode 27.

Crystal piece 24 with electrodes 26, 27 is mounted within a cylindrical recess 28 of an electrical insulator 29, for instance of glass or ceramic material. Recess 28 is continued by a larger recess 30 into which a metal ring 31 is fitted, e. g. screwed or cemented. Ring 31 is supported in vessel 17 by means of four radial spokes 32 which in this exemplification of the invention are made particularly cast in one piece with the lower part of vessel 17.

The outer contour of insulator 29 may be streamlined and is continued by the smooth outer surface of ring 31 into its opening 33 in front of surface 25 of vibrator 24, leaving a narrow passage 76 between the insulator and the wall of vessel 17. A hole or bore 34 in insulator 29 is passed by a conductive bolt or rod 35 whose lower end projects into recess 28 to form a rivet 36 which holds in place a flat spring 37. This spring comprises in this example four springy arms which rest upon electrode 27 and press piece 24 against the inwardly projecting rim of ring 31. The upper end 38 of rod 35 is screw-threaded and projects outside the top of insulator 29 and recess 39 in it. Two nuts 40, 41 are screwed upon the screw-threaded end 38. Nut 40 engages recess 39 and holds rod 35 and spring 37 in place relative to insulator 29. A conductor 42 is clamped between nuts 40 and 41 and leads to a rod 43 passing an insulator 44, for instance of glass or ceramic material. This insulator comprises a cylindrical portion passed through a hole 45 in the wall of vessel 17; an insulating ring 46 is fitted upon the projecting inner end of that cylindrical portion and held in place by nut 47 screwed upon the inner end of rod 43. The end of lead 42 is conductively connected with rod 43. Nuts 48, 49 are screwed upon the outer end of rod 43 and a terminal 50 is clamped between them. A vacuum sealing compound may be suitably applied in all the gaps between insulating ring 46, insulator 44, wall of vessel 17, rod 43, and nuts 47 and 48.

A conical hood 51 is slipped over and fastened at 53 to the top of insulator 29 and covers the projecting end 38 of rod 35, and the nuts thereon. Thereby the streamlined shape of the vibrator unit is completed and back-reflection of gas molecules toward jar 10 is prevented. The hood may consist of metal or insulating material; in the former case, lead 42 is to be insulated from the hood. Hood 51 is provided with a few small holes (not shown) through which its interior communicates with the surrounding space. Hood 51 can be dispensed with if the end 38 and nuts 40, 41 are fitted into the streamlined contour.

A set of baffles 54 can be arranged above hood 51 as shown more in detail in Figs. 5 and 6; they also serve to prevent back reflection of gas molecules into jar 10.

Any type of generator of recurrent electric impulses or oscillations can be used for exciting the mechanical resonance vibrations of piece 24. Fig. 1 exemplifies the diagram of a Hartley circuit. It comprises in its most simple form and essentially a triode 55 with cathode 56, grid 57 and plate (anode) 58. 59 is a (regulable) source of current for heating cathode 56; 60 a (regulable) source of plate current; 61 a make-and-break switch for starting and interrupting the oscillations; 62 a resistance in the heating circuit of the cathode from which, through leak resistance 63 and adjustable tap 64, a desired bias of grid 57 can be derived; 65 is a block condenser; 66 a self-induction coil and 67 an adjustable condenser, and together they form an adjustable oscillation circuit which determines the frequency and maintains the generation of the oscillations; 68 is an (adjustable) tap for connecting a desired point of coil 66 with the positive terminal of source 60. One end of coil 66 and condenser 67 is connected by conductor 69 with terminal 50, while the opposite end of coil 66 and condenser 67 is connected by conductor 70 with terminal 80 clamped between nut 74 and flange 72. Thus the oscillating voltage generated is applied through conductor 69, terminal 50, rod 49, lead 42, rod 35 and spring 37 to electrode 27, and through conductor 70, terminal 80, vessel 17, spokes 32, ring 31 to the other electrode 26. If anode 58 is to be grounded, conductor 69 will be connected with terminal 80 and vessel 17, and conductor 70 with terminal 50. However this connection be, by adjusting condenser 67, the frequency generated can be varied; by adjusting tap 64 and/or tap 68 the oscillation energy generated and thereby the mechanical vibration energy of piece 24 can be varied. Other means and arrangements for generating supersonic oscillations of desired high frequency and energy can be used instead of the ones illustrated.

In the example shown in Figs. 1 and 2, vessel 17 is sub-divided into an upper and lower portion which are connected by means of flanges 71, 72 and bolts 73 provided with nuts 74. A vacuum sealing compound 75 may be provided between the contacting flanges 71, 72. This sub-division permits convenient mounting of the vibrator unit and its supports within vessel 17, and replacing or exchanging of the former for repair or desired change e. g. of frequency and/or exposed active surface area.

In operation, after bell-jar 10 has been airtightly positioned upon pump plate 11 and valve 14 closed, the backing pump 21 is started by switching in motor 22, and gradually rarefies the gas (air) enclosed in the first or upper confined space comprised of the interior of jar 10, pipe 13 and space 78 within vessel 17 back of insulator 29 and the vibrator unit, as well as in the second or lower confined space 77 within vessel 17 in front of the freely exposed surface 25 of vibrator 24; the first named confined space communicates through passage or gap 76 with the second confined space and the latter through duct 20 with the suction or intake side of pump 21.

After the gas has been rarefied in all the communicating confined spaces named almost to the limit of low pressure attainable by the backing pump, e. g. 10^{-1} to 10^{-2} millimeters mercury column, switch 61 is closed and thereby vibrator 24 and its surface 25 excited to supersonic vibrations of adjusted energy. At the low pressure produced by pump 21, the gas (air in this example) is rarefied to an extent that the average path of free flight of its molecules, i. e. until they collide with one another, or their "mean free path" is in the order of or exceeds the dimensions of passage 76.

It will be seen from Figs. 1 and 2 that vibrator 24 is completely screened or covered against the first confined space as defined above, particularly space 78, and also against passage 76 by insulator 29 and ring 31. Its surface 25 is solely exposed toward the second confined space 77. The direction of the supersonic vibrations of surface 25 is essentially perpendicular to it, and their effective outward stroke is directed toward space 77 and away from passage 76.

If gas molecules impinge upon the vehemently vibrating surfaces 25, the impact of the latter imparts to them a velocity component in the direction of those vibrations, viz. toward space 77 and away from passage 76. These gas molecules are thereby projected into space 77 in the direction of arrows 75 and, since surface 25 vibrates with high velocity and acceleration at supersonic high frequency and it impacts upon impinging gas molecules recur extremely fast, the number of projected gas molecules will be considerable and result in instantaneous, at least local reduction of gas pressure in front of surface 25 and sufficiently close to the discharge end of passage 76 into space 77, to cause diffusion of gas molecules from the first confined space, including space 78, through passage 76 in the direction of arrows 79 toward the front of vibrator 24. Many of the thus diffused gas molecules impinge upon surface 25 and are projected into the second confined space 77 wherefrom they are removed by backing pump 21. Some diffused gas molecules will hit the wall of vessel 17 and be reflected toward surface 25 which throws them into space 77 wherefrom they are removed by pump 21. Only a few diffused gas molecules will return through passage 76 into space 78. Thus the ratio of returning or re-diffusing gas molecules to those effectively removed from space 77 will be very small, particularly if the passage space or area 76 is sufficiently small compared with the effective area of surface 25.

The concurrent phenomena of gas removal just described recur in the frequency of the vibrating surface 25. By proper choice and adjustment of that supersonic frequency and its amplitude, depending inter alia on the kind of gas or vapor undergoing rarefaction, the dimensions of the spaces and the degree of high vacuum to be produced, optimum effects can be attained and the speed of evacuation controlled. The frequency can be varied stepwise by changing the frequency of the oscillation generator from a value corresponding to the fundamental mechanical resonance frequency of the vibrator 24 to any odd (higher) harmonic thereof, e. g. by adjusting condenser 67. The desired amplitude of the mechanical vibrations can be obtained by adjusting positions of tap 64 on resistor 62.

If it were possible to direct and project all the molecules impinging upon surface 25 into the backing pump, no back-diffusion could occur through passage 76, and an almost complete vacuum could be attained. In practice, the back-diffusion and the low pressure limit of the backing pump also limit the degree of highest vacuum attainable in the first confined space including bell-jar 10 by means of a single vibrator pump stage. If higher or highest vacua and/or pumping speeds are desired, two or more vibrator units can be arranged in series. Fig. 3 exemplifies the arrangement in series of two such vibrator units.

Insulator 90 is cone-shaped with its point within space 78 of vessel 82, and is provided with a lateral bore 91 through which a lead 92 is passed the end of which contacts spring 37 and is riveted with it to bolt 93 positioned within an axial bore 94 of insulator 90. Lead 92 projects air-tightly through an insulator 94 which is air-tightly sealed by means of a vacuum sealing compound 95 into an opening 96 of vessel 82. The outer end of lead 92 is screw-threaded and two nuts 97 and 98 screwed upon it between which terminal 50 is clamped.

Piezo-electric vibrator 24 is cut and shaped in the same manner as described with reference to Figs. 1, 2 and provided with electrodes 27, 26 and supported by the projecting rim of ring 31.

The tapered upper end 81 of vessel 82 fits into the lower end 15 of pipe 13 connected e. g. with a pump plate in the manner shown in Fig. 1. The lower part of vessel 82 expands and ends in flange 83. The upper part 89 of vessel 84 is cup-shaped and ends in flange 85 which is air-tightly connected with flange 83 by means of an interposed vacuum sealing compound 88 and bolts 86 with nuts 87 tightened thereon. In similar manner the lower portion of vessel 84 is expanded and ends in flange 100, while the upper cup-shaped end 101 of the next following vessel 99 ends in flange 102, which is air-tightly connected with flange 100 in a manner similar to the one explained with respect to flanges 83, 85. The adjacent and connecting portions of vessels 82, 84 and 84, 99 are obviously identical and therefore the same reference numbers are used henceforth for identical parts of and in them; only those within vessels 82, 84 shall be described more in detail.

The lower portion of vessel 82 and the cup-shaped upper portion 89 of vessel 84 are shaped so as to confine, together with insulator 90 and its supporting ring 31, a narrow passage 76. In particular, cup-like portion 89 is continued to form an edge 103 of a diameter essentially the same or slightly larger than the innermost diameter of opening 33, i. e. the diameter of the effective vibrating surface. Apart from this, the shape and assembly of ring 31 with inwardly projecting rim, ring-shaped electrode 26, cylindrical piezo-electric crystal piece 24, electrode 27, spokes 32 and spring 37 in the recesses 28 and 30 of insulator 90, are essentially the same as described hereinbefore with reference to Figs. 1 and 2. Spring 37 and lead 92 are threaded and riveted upon pin 93 positioned within a recess of the insulator. Lead 92 extends laterally through a narrow passage 91 in insulator 90. Lead 92 continues through another insulator 94, preferably of glass or ceramic material which is fitted into an opening 96 of vessel 82 and sealed therein by a suitable vacuum sealing compound 95. Lead 92 is also sealed by such a compound into insulator 94, and onto its outwardly projecting screw threaded end nuts 97, 98 are tightened, clamping between them terminal 50.

The top of insulator 90 is cone-shaped and pointed, so as to permit gas molecules to fly in the direction of arrows 104 to passage 76 and to substantially prevent their reflection back towards pipe 13.

Passage 76 is continued around the lower surface of ring 31 and ends with edge 103 in front of the piezo-electric vibrator 24. Hence the gas molecules diffusing in the direction of arrows 104 are guided in the direction of arrows 105 almost completely to the front of vibrator 24 and its vibrating surface 25, impinge upon the latter and are accelerated in the direction of arrows 106 toward insulator 90' below. Deflection of gas molecules toward and their diffusion back through passage 76 into space 78 back of insulator 90, is thereby prevented to a larger extent than by the structure shown in Fig. 1; passage 76 is considerably longer and the separation between the incoming and projected gas molecules is improved.

The terminals 50 of the vibrator elements of both stages are assumed to be connected with one terminal of an electrical oscillation generator, while the vessels 99 and 84 and thereby the rings 31 and electrodes 26 in contact therewith are connected by terminal 80 to the other terminal of the generator.

In operation, and after the pre-vacuum has been established in the manner described with reference to Fig. 1, the vibrator elements 24 are actuated by switching in the oscillation generator. It is assumed in this exemplification of the invention that the piezo-electric elements are identical as to shape and mass and consequently excitable to the same resonance frequency which is either the fundamental or a harmonic thereof. Though the supersonic or high frequency of the vibrators is thus the same, the energy of their vibrations may be the same or different, and in the latter event, e. g. the vibrating energy of the lower vibrator larger than that of the upper one. This can be obtained by arranging in conductor 107 an adjustable resistor 108. Inversely, the upper vibrator may be more strongly excited by corresponding control means. The vibrators can also be excited individually and independently by separate high frequency generators. The sizes or areas of the effective vibrating surfaces 25 may be identical or different.

It will be appreciated that to the gas molecules impinging upon the vibrator surface 25 of the upper vibrator element will be imparted a velocity component directed toward the lower insulator 90', across and away from the discharge end (gap) of passage 76 close to surface 25. Thereby the space in front of vibrating surface 25 is depleted of gas molecules and a suction effect instantaneously produced. The gas molecules projected from vibrating surface 25 also fly across and away from the adjacent discharge end of passage 76 and are apt to produce a kind of ejector effect aided by the particular shape of the discharge end of passage 76 as shown. In any event, diffusion of gas molecules from space 78 through passage 76 into space 77 results, and only a very small fraction of the gas so diffused will revert or diffuse back through passage 76 into space 78.

As a result, the amount of gas molecules in space 78 and thereby the pressure therein are reduced.

The effect of vibrating surface 25' of the other, lower vibrator 24' is essentially the same as just described with reference to the upper vibrator 24, and will result in the diffusion of gas molecules projected in the direction of arrows 106 within space 77 through passage 76' in the direction of arrows 109 into space 111. The gas molecules in the latter space are acted upon and projected by vibrating surface 25' in the direction of arrows 110. The gas molecules entering space 111 are finally removed by the backing pump 21 connected with this space through intake 20.

Assuming that the backing pump is capable of producing a vacuum of 0.1 mm. mercury column, and assuming further that each vibrator stage of the pump can produce and maintain a ratio of pressures in the spaces in front and in

the back of the vibrator element or unit, equalling 1000, then a pressure of 10^{-4} mm. mercury will be obtained in space 77 and a pressure of 10^{-7} mm. mercury in space 78 which is a high vacuum sufficient for most applications.

In Fig. 4 a multi-stage pump is exemplified according to the invention. Similar parts used as in Fig. 3 are identified by identical reference numbers. The uppermost or first confined space 78 is connected with a manifold 113. Bulbs (shown in dotted lines) to be evacuated are connected with the outlets 114. The bulbs may be for incandescent lamps, electronic tubes, cathode ray tubes, etc. They are melted or sealed off after evacuation in a well-known manner.

In this exemplification of the invention, metal vessels 82, 115, 84 are connected through ground with one oscillating potential of an oscillation generator, and through rings 31 and preferably ring-shaped electrodes with each vibrator (piezo-electric element) 24, 116, 24'. The other electrodes 27 on each of the vibrator elements are individually connected through leads 92, 117, 118 with terminals 50, 119, 120, and each terminal is individually connected through conductors 121, 122, 123 with equal or different potentials of the oscillation generator. These different potentials may be derived either from a single oscillatory circuit by tapping therefrom different voltages, or from different circuits which may also be tuned to different frequencies. Thereby the vibrator elements can be excited with different energies and/or to different supersonic frequencies. When different frequencies are applied to the vibrator elements, their thicknesses must be different in order to respond in resonance to those exciting frequencies; if the thicknesses are identical, higher harmonics can be used for excitation.

It will be appreciated that in the lowest or last confined space 124 the highest of the low pressures is produced and maintained by means of an auxiliary or backing pump. The low pressures in the spaces 125, 126 and 78 will decrease in the order named so as to produce the lowest pressure or the highest vacuum in space 78 communicating with the interior of manifold 113 and the containers (bulbs) communicating therewith.

It is to be understood that by increasing the number of the vibrator pump stages, the ultimate vacuum attained in space 78 can be increased and, e. g. with three such stages, vacua of 10^{-8} mm. mercury column, or less, attained within a short period of time.

It should be understood that the invention is not limited in any way to the exemplifications shown or any theory propounded herein, but is to be derived in its broadest aspects from the appended claims. Various changes can be made within that scope. Thus, instead of piezo-electric elements exemplified herein in their most simple form, piezo-electric vibrator units can be used comprised of one or more properly cut pieces of piezo-electric material (quartz) and cemented upon or between plates of metal (particularly steel) one of which forms the exposed surface (25). Reference is made in this respect to the description and illustrations in my copending application Ser. No. 500,242. Instead of the use of piezo-electric oscillators to form the vibrator unit or part of it, magneto-striction oscillators can be used and in particular a vibrator as described and illustrated in my said copending application, Fig. 7. There is also the possibility of using the vibrating surface of a membrane, partly or entirely of magnetic material, as described and illustrated in my said copending application with reference to Fig. 3 thereof. Instead of metal, such as iron or steel, as shown for the walls of the vessels 17, 81, 82, 84, 115, etc., glass, ceramic and other suitable materials can be used.

What I claim is:

1. In a method of rarefying gas in a first confined space communicating with a second confined space, the steps of producing and maintaining in the gas in said second space a moderately reduced pressure, producing energy vibrations at supersonic high frequency, and applying the vibrational energy in a mean direction away from said first space to gas molecules in said second space to impart to said gas molecules velocity components in said direction away from said first space and cause diffusion of gas molecules from said first into said second space resulting in rarefaction of the gas in said first space.

2. In a method of rarefying gas in a first confined space communicating through a narrow passage with a second confined space, the steps of producing and maintaining in the gas in said second space a moderately reduced pressure of a value at which the mean free path of the gas molecules exceeds the dimensions of said passage, producing energy vibrations at supersonic high frequency, and applying the vibrational energy in a mean direction away from said first space to gas molecules in said second space to impart velocity components to said gas molecules essentially in said direction and promote diffusion of gas molecules through said passage from said first into said second space resulting in rarefaction of the gas in said first space.

3. In apparatus for reducing the pressure of gas in a first confined space communicating through a narrow passage with a second confined space, means exemplified by an auxiliary pump for maintaining a moderately low pressure in said second space, an electrically excitable mechanical vibrator in said second space having a surface element exposed towards said second space and arranged close to the discharge end of said passage, and means for electrically exciting said vibrator and thereby its exposed surface element to vibrations of supersonic frequency in a direction essentially away from said discharge end and perpendicular to said surface element.

4. In a method of reducing the pressure in the gas contained in a series-arrangement of at least three confined spaces including a first and a last space and communicating through narrow passages arranged between each adjacent pair of them, in the first of which the lowest pressure is to be produced, the steps of producing and maintaining in the gas in the last of said spaces a pressure at a level at which the mean free path of the gas molecules exceeds the dimensions of said passages, producing energy vibrations at supersonic high frequency in said second to last spaces and in a direction away from an adjacent passage of lower order number, and applying the vibrational energy to gas molecules in each of said second to last spaces and close to the discharge end of a passage to impart velocity components to gas molecules in each of said second to last spaces in said direction and promote diffusion of gas molecules through each of said passages from a connected space of lower order number into that of next higher order number, resulting in reduction of pressure in the gas in each space from which it diffuses and lowest pressure in the gas in the first space.

5. In a method of rarefying gas in a first confined space communicating through a narrow passage with a second confined space, the steps of prerarefying the gas in said second space to a degree at which the mean free path of the gas molecules exceeds the dimensions of said passage, producing energy vibrations at supersonic high frequency close to the discharge end of said passage and in a direction away from said discharge end, and applying the vibrational energy to gas molecules in said second space to impart velocity components in said direction to said gas molecules in said second space and locally deplete of gas molecules a portion of said second space where said vibrations are produced close to said discharge end, resulting in diffusion of gas molecules through said passage from said first into said second space toward its depleted portion and increased rarefaction of the gas in said first space.

6. In a method of producing a difference of high vacuum pressure in gas confined in a first and a second space which communicate through a narrow passage, the steps of prerarefying the gas in said communicating spaces to a degree at which the mean free path of the gas molecules exceeds the dimensions of said passage, producing energy vibrations at supersonic high frequency and in a direction away from said passage and first space, and applying the vibrational energy to gas molecules in said second space to impart velocity components to said acted upon gas molecules in said direction away from said passage resulting in promotion of diffusion of gas molecules through said passage from said first into said second space and increased rarefaction of the gas in said first space.

7. In apparatus for producing a high vacuum in a container by means of a molecular high vacuum pump and an auxiliary vacuum pump, a high vacuum pump essentially comprising a first confined space communicating through a narrow passage with a second confined space and said auxiliary pump, the dimensions of said passage smaller than the mean free path of the gas molecules at the reduced pressure to be produced by said auxiliary pump, a piezo-electric vibrator unit arranged in said second space close to the discharge end of said passage, said unit provided with a surface element exposed towards said second space and capable of vibrating essentially in a direction perpendicular to its exposed surface and away from said passage and first space, and electrical means for applying oscillatory electric energy of selected supersonic frequency to said vibrator unit for exciting it and thereby its surface element to mechanical vibrations of said frequency or a harmonic thereof and essentially in said direction.

8. An apparatus for producing a high vacuum in a container, essentially comprising a vessel the interior of which is subdivided in a first and second space communicating through a narrow gap, means for connecting said first space of the vessel with a container to be evacuated, means for connecting said second space of the vessel with a pre-vacuum pump, a mechanical vibrator capable of being electrically excited to vibrations of selected supersonic frequency mounted within said vessel and provided with an exposed surface element arranged close to said gap and facing said second space, said surface element capable of vibrating in a direction es-

sentially perpendicular to it, and electrically conductive means for connecting said vibrator with a source of oscillatory electrical energy of said selected supersonic frequency.

9. An apparatus for producing a high vacuum in a gas within confined space, including a vessel the interior of which is subdivided in a first and second space communicating through a narrow gap, means for connecting said first space with the confined space to be evacuated, means for connecting said second space of the vessel with a pre-vacuum pump, the dimensions of said gap being smaller than the mean free path of the molecules of said gas at pre-vacuum pressure to be produced by said pump, a piezo-electric vibrator element capable of being excited to mechanical vibrations of selected high frequency within said vessel, means as exemplified by an electrical insulator supporting and covering said vibrator element but leaving exposed a surface element of it, said surface element close to said gap and facing said second space, said vibrator element capable of vibrating in a direction essentially perpendicular to said surface, and electricallly conductive means for connecting said vibrator element with a source of electrical oscillatory energy of said selected high frequency.

10. An apparatus for producing a high vacuum in a gas in within confined space, including an elongated vessel, at least one piezo-electric vibrator element capable of being excited to mechanical vibrations of selected supersonic frequency, means as exemplified by an electrical insulator for supporting within said vessel and covering said vibrator element but leaving exposed a surface element of it, said vibrator element and supporting means arranged within said vessel so as to leave a narrow gap between them and said vessel, said surface element capable of vibrations in a direction essentially perpendicular to it, electrically conductive means for connecting said vibrator element with a source of electric oscillatory energy of said selected supersonic frequency, means in the back of said supporting means for connecting in open communication said vessel with a container to be evacuated, and means in front of said vibrator element and its exposed surface element for connecting in open communication said vessel with another pump space.

11. For use with a container of gas to be rarefied and a pre-vacuum pump, an elongated vessel open at opposite ends, the first of said ends to be connected with the container and the second of said ends to be connected with the pre-vacuum pump, said vessel comprising at least two spaces communicating through a narrow passage, the first of said spaces communicating with said first end and the second of said spaces communicating with said second end, a mechanical vibrator capable of being electrically excited to vibrations of supersonic high frequency mounted within said vessel between said spaces and surrounded by said passage, said vibrator having a surface element arranged close to said passage and facing and exposed to said second space, said surface element capable of vibrating in a direction essentially perpendicular to it, and electrically conductive means for connecting said vibrator with a source of oscillatory electrical energy for exciting said vibrator.

12. The combination including a container for

gas to be rarefied, a pre-vacuum pump, and a vessel, said vessel at a first place communicating with said container and at another second place communicating with said vacuum pump, said vessel comprising at least two spaces communicating through a narrow passage, the first of said spaces communicating with said first place and the second of said spaces communicating with said second place, a mechanical vibrator capable of being electrically excited to vibrations of supersonic high frequency mounted within said vessel and provided with an exposed surface element arranged close to said passage and facing said second space, said surface element capable of vibrating in a direction essentially perpendicular to it and away from said passage and first space, and electrically conductive means for connecting said vibrator with a source of oscillatory electrical energy for exciting said vibrations.

13. The combination including a container for gas to be rarefied, a pre-vacuum pump, a source of oscillatory electrical energy, and a vessel, said vessel at a first place communicating with said container and at another, second place communicating with said pre-vacuum pump, said vessel comprising at least two spaces communicating through a narrow passage, the first of said spaces communicating with said first place and the second of said spaces communicating with said second place, a mechanical vibrator capable of being electrically excited to vibrations of supersonic high frequency mounted within said vessel and provided with an exposed surface element arranged close to said passage and facing said second space, said surface element capable of vibrating in a direction essentially perpendicular to it and away from said passage and first space, and electrically conductive means for connecting said vibrator with said source of oscillatory electrical energy, said ocillatory energy adapted to excite said vibrations.

14. In a method of rarefying gas in a first confined space communicating with a second confined space, the steps of producing and maintaining in the gas in the second space a maximum pressure of about 10^{-1} millimeters mercury column, producing energy vibrations at a frequency of about 100,000 to 10,000,000 cycles per second in a direction away from said first space, and applying the vibrational energy to gas molecules in said second space to impart velocity components to said molecules in said direction and thereby cause diffusion of gas molecules from said first into said second space, whereby the gas in said first space may be rarefied and its pressure reduced to below about 10^{-4} millimeters mercury column.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,433,258	Buckley	Oct. 24, 1922
1,729,579	Hayes	Sept. 24, 1929
2,312,712	Hartline	Mar. 2, 1943
2,152,241	Coons	Mar. 28, 1939